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Sustainable management of energy crops for integrated biofuels and green energy production in Greece

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ABSTRACT

The present work deals with the assessment of the sustainability and integrated management of four energy crops and their residues, in Greece. Pilot agronomic experiments were performed by cultivating cotton, sunflower, soya and rapeseed for the estimation of their sustainability towards biofuels production and using their residues as feeding materials in a laboratory scale gasifier for the estimation of their bioenergy production potential. Fertilization needs, harvesting techniques, crop productivity and oil yields were recorded. The crops were cultivated under "farm" conditions in several demonstration fields. The study indicated that proper use and integrated management of the above energy crops and their residues, for the production of vegetable oil and bioenergy, respectively, could result in increase of the domestic raw material production for the biodiesel industry and enhance the cohesion of agriculture, energy and environmental policies in Greece.

Contents

1. Introduction

Latest energy policy developments reflect the tendency to increase energy production share from renewable energy sources (RES), not only for strategic, but also, for environmental and socio-economic reasons. Biomass currently contributes only 4% to the total energy demand in Europe, while 2–15 tons/ha of dry biomass is produced annually [1]. Moreover the European member states set climate change prevention goals by voting a new Directive aiming at a 20% reduction in greenhouse gases (GHG), compared to 1990 levels, a 20% cut in energy consumption through improved efficiency energy production methods and a final 20% increase in

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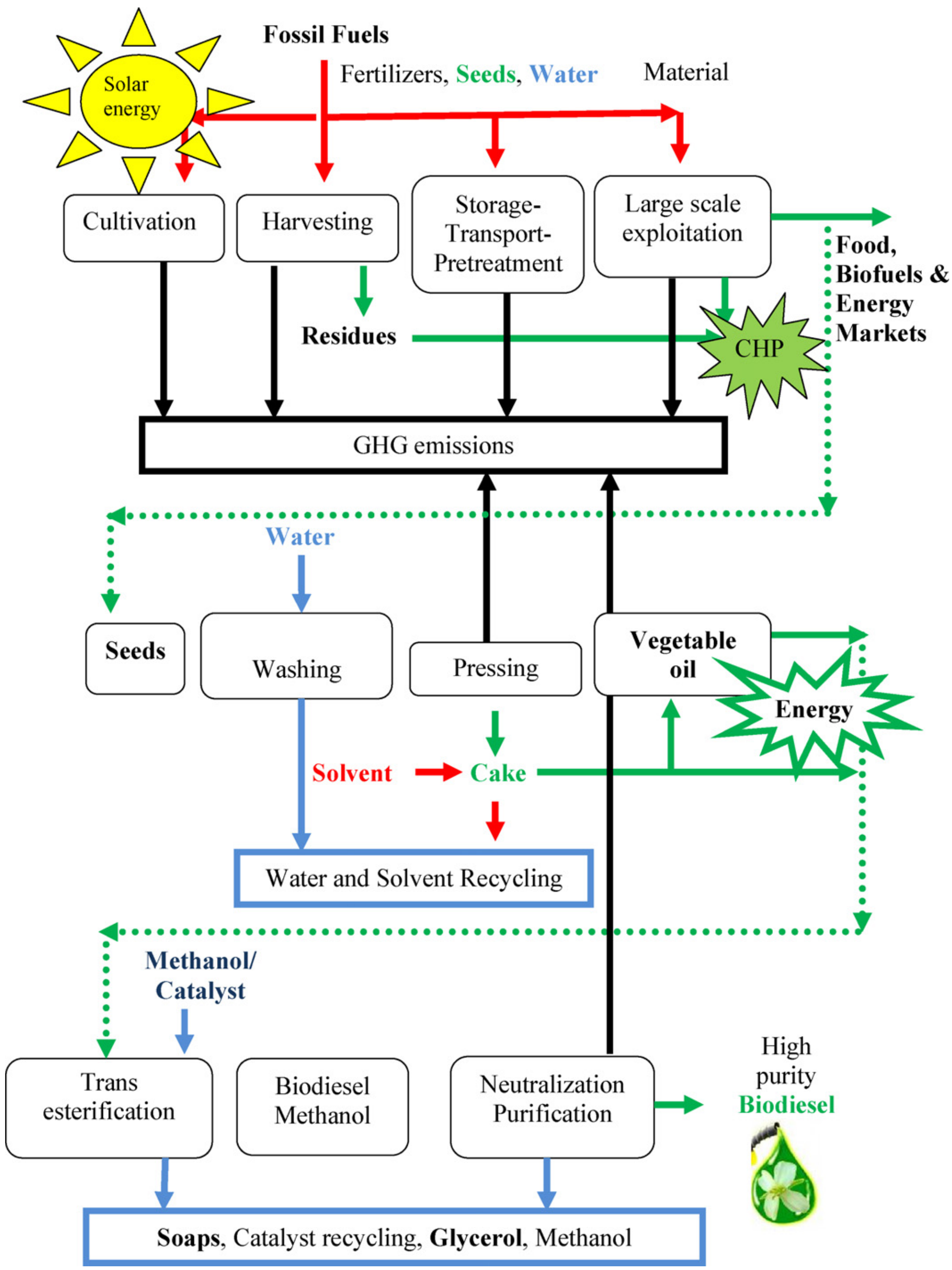


Fig. 1. Simplified scheme of biofuel and bioenergy production chain from energy crops and their residues.

the use of RES by the year 2020. This directive requires from the fuel suppliers to reduce GHG emission caused by extraction or cultivation, including land use changes, transportation and distribution, processing and combustion of transport fuels. Reduction of GHG emissions could be achieved by using more biofuels and other alternative fuels [2].

The energy crops cultivation may well alleviate the crisis that European agriculture sector faced lately [3]. Although considerable efforts have been made to embody energy crops in biofuel and bioenergy production, their implementation is still rather slow across Europe [4]. Thorough researches over bioenergy chains embodiment in different geo-climatic conditions and areas should be accomplished prior to decision making in biofuels production and furthermore their full scale promotion in domestic markets.

The three different categories of energy crops (oil, cellulose and sugar containing plants) lead to liquid, gaseous and solid biofuels production; thus they can be incorporated in biodiesel and bioenergy production chain, as Fig. 1 indicates. Vegetable oil extracted from species such as soyabean, sunflower, rapeseed and cotton can be refined as biodiesel, utilized in mixtures with transport fuels or burned directly as heating fuels. The cake from vegetable oil production is usually utilized as feed, while residues (energy crop stalks and leaves) could be burned directly or exploited by gasification in order to produce energy of high efficiency in a combined heat and power production system.

However, information concerning the adaptability of new energy species, the respective crop inputs like energy (diesel fuels), chemicals (fertilizers, pesticides), natural sources (land and water

availability), the crop left over (availability of remaining residues on fields) and the energy saving potential should be evaluated together in an integrated scheme of green energy production. Thus, crop residues could contribute to meet the energy demand requirements of countries applying wide agriculture activity, like Greece. Energy crop residues produced from large scale cultivations could be considered as alternative options in green energy production, not only for creating job positions, enhancing rural development and increase industrial activities, but also, for offering higher yields and efficiencies than conventional crops. Their productivity per hectare is higher than other crops and when dealing with energy production, they present homogeneity in physicochemical characteristics which is an important issue for energy production units. Exploitation of energy crops and residues is assumed to increase biodiversity and may contribute to farmers income increase. All the above issues consist the frame within this study was enrolled.

2. Literature review

Wide scientific literature deals with energy crops and vegetable oil production. Pure vegetable oil is obtained from oil seeds, as Fig. 1 indicates, and the process is similar to the production of nutrition oils by solvent extraction and cold pressing, while a feed cake is produced as by-product. The solvent is recycled and pure vegetable oil can be used in automobile engines without using additives or changing its molecular structure. Thus, several types of vegetable oils have been previously studied for direct use in engines as rapeseed oil, jathropha oil [5], coconut oil [6], gum oil [7], cotton seed oil [8] and even used frying oils [9].

Biodiesel is produced from vegetable oils (Fig. 1), while glycerol is produced as by-product of high added value for pharmaceutical and cosmetic industry, and even energy production [10]. In the case of Greece direct utilization of vegetable oils has been proposed for tobacco stems [11], tomato seeds [12]. In Spain, Grau et al. [13] have investigated the large-scale production of first-generation biodiesel from rapeseed and showed the difficulties due to the increased land requirements, competition with food industry, fertilizer requirements; however they concluded that those barriers did not necessarily apply to small-scale productions. Xu and Hanna [14] indicated the attractiveness of hazelnut oil for biodiesel production with calorific value of 40 kJ/kg that accounted for 88% of the diesel's energy content. However most of the research works have been focused on rapeseed oil utilization in diesel engines.

There are few research studies that indicate the ability of energy production from energy crop residues (stalks and leaves) [15–19]. A short literature review concerned recent attempts of energy crop residues utilization for energy production and shed light to the fact that such information is relatively scarce to the worldwide scientific literature. Among others, Zabaniotou et al. [15] referred to the ability of upgrading soya and sunflower residues into solid biofuels for energy production by gasification, while Sanchez et al. [20] investigated the utilization of pyrolysis product (char) of sunflower for soil management. Sharma-Shivappa and Chen [21] indicated that residues from cotton fields and gins resulted in, not only, increased environmental problems due to disposal issues, cotton diseases and pests evaluation, but also, distracted the cultivation due to slow decomposition in the soil. Studies also suggested that composition of cotton residue (stalks or ginning waste) was similar to other lignocellulosic feedstock, and it thus had the potential to be used as an energy source through thermochemical treatments. A review of the various conversion processes suggested that although cotton waste was suitable for the production of a variety of products, in-depth investigation of energy production at pilot scale seemed essential to determine the process' efficiency and economic feasibility. On the other side, Jingura and Matengaifa [22] highlighted, not only the importance of crop residues utilization to increase the balance of bioenergy production in their country, but also, the need to balance use of crop residues for both energy and other purposes such in animal feeding and soil fertility improvement. Zabaniotou et al. [19] and Zabaniotou et al. [23] referred to the viability of energy production from cotton ginning and other agricultural residues in pilot scale, for countries with rough topography based in agricultural activity like Greece. Additionally, Petrou and Mihiotis [24] proved that the substitution of conventional fuel by cotton stalks in the industry sector is feasible technically and economically. Finally, Akdeniz et al. [25] stated that an establishment of well organized biomass (cotton residue) management would be helpful for the optimum use of agricultural residues in energy production sector.

The aim of the present work was to investigate the sustainability of energy crops cultivation in Greece and the evaluation of the possibility of parallel bioenergy production from their residues.

3. Methodology

The methodology used in order to approach the issues concerning the sustainability of energy crops cultivation in Greece and the possibility of residues incorporation in an integrated biofuel and bioenergy production chain (Fig. 1) was as follows:

(a) review of the other countries experience
(b) selection of the proper species for large scale cultivation in Greece
(c) agronomic aspects of cultivation (varieties, yield potential, cultivation techniques, growing areas selection
(d) potential energy production potential from crop residues by gasification and
(e) estimation of the energy saving potential by exploitation of the syngas produced from energy crop residues.

A biofuel and bioenergy production chain can be divided into stages containing energy crop cultivation, product harvesting and transport, pretreatment and large scale processing either for vegetable oil or for energy production. Inputs (fuels, fertilizers, water, seeds etc.) and outputs (GHG emissions, useful energy and by-products) that should be taken into consideration in an integrated scheme are presented in Fig. 1. Residues can be used directly for energy production, if profitable, instead of being left in fields leaving unexploited their energy content.

The balance between inputs and outputs is the critical index for the sustainability of the energy crops cultivation. Conditions for growing energy crop specie in a region, choice of the hybrid to cultivate and selection of agriculture technique are important issues for reaching a successful outcome. The energy crops land planning has to be taken into account as well. Growing the energy crops away from the energy production site where the residues can be exploited leads to increased logistics and thus influences biofuels cost in an integrated perspective; in such case small and decentralized energy production units might, in the future, comprise viable solutions in distributed energy production from agricultural biomass.

Additionally environmental effects of the introduction of new specie in a region have to be taken into account, e.g.: water deposit balance, water pollution, competition with food industry, soil preservation and chemicals use. Therefore, a thorough integrated study from cultivation to biofuel production and alternatives as well a LCA should be accomplished prior to establishment of the new crop, in order to ensure its sustainability. In this study LCA has not performed but it is intended to be carried out based on the data collected in this study.

3.1. Crops cultivated in the study

Four potential energy crops were selected for large scale cultivation based on the results and adaptability information [26,27], as well as on previous on field experience [28] in Greece. Cotton, sunflower, rapeseed and soyabeans were cultivated in various regions of Greece (e.g. Thrace, Eastern, Central and Western Macedonia, Thessaly and Central Greece) by Pioneer Hi-Bred Hellas S.A. The selection of species hybrid or variety to cultivate was made by taking into account previous experience and related information regarding the Greek geo-climatologic conditions. The target was to select the best hybrid/variety per crop with respect to genetic and phenotypic characteristics, taking into account, at the same time, the ability of producing high quality and quantity of products. The adaptability of each crop was investigated for the specific region and climate, while essential information for efficient crop management (seeding, fertilization, irrigation) was recorded. Products (crops and residues) were stored and treated appropriately (pressed for oil extraction, dried naturally in air respectively) for further use. It has to be mentioned that only the rapeseed is a new crop for Greece, the other three being the already known adapted in Greek conditions.

3.1.1. Rapeseed

Rapeseed (*Brassica napus*) is the most cultivated energy crop in Europe grown for the biofuel, food and fodder industry. Rapeseed's high oil yield is attributed to its high cellulosic content [29] and, consequently, rapeseed is at the moment the first option for biodiesel production [30], while it may be the only, at the moment, able to be used without prior treatment as liquid biofuel. Rapeseed oil covers 12% of the world oil market, while production in Europe reaches 35%, in China 26%, in India 14% and Canada 8% [31].

Rapeseed is cultivated in north-central Europe areas and in some southern areas where it could be an alternative to other cultivations. Even though the total cultivated area of rapeseed is still small, its adaptability and satisfactory yield makes it an attractive alternative cultivation for farmers and a very good feedstock for biofuels production.

Rapeseed was introduced in Greece in 2006. After the extraction of oil from rape the seeds (30–50%ww) the rapeseed cake is produced (by-product) and used as animal feed due to its high proteinic content (10–45%ww).

For the purpose of the present study, five hybrids of rapeseed (PR45W04, PR46W09, PR46W10, PR46W31 and PR45D01) provided by Pioneer Hellas were cultivated during the period of 1st of October until 10th of December. Cultivation took place in 11 demonstration fields in order to evaluate rapeseed all over Greece. Little information in rapeseed adaptability in Greek climatologic conditions was available. Planting was performed by planters that are used for winter cereals. Plant density fluctuated from 36 to 109 plants/m^2. First plants emerged after 8–11 days from seeding. Late seeding (18–21 November) in Western and Central Macedonia resulted in stand establishment failure. Low temperatures in high altitude (from 625 to 710 m) and lack of precipitation led to delays in plant emergence (>20 days). Frost (<−5 °C) killed the young plants. Pre plant N–P–K application was applied. The main recorded weeds were: *Avena* spp., *Sinapis* spp. and in some cases *Chamomilla recuita*, *Fumaria* spp., *Digitaria sangualis* and *Cunodon dactylon*. The rapeseed cultivation faced several enemies with the most common ones being Aphids, *Brevicoryne brassicae* and Pentatomidae and in some cases *Phyllotreta striolata*. No diseases were noticed to any of the cultivated fields.

3.1.2. Soya beans

The cultivation of soya beans (Cycline Max) was first attempted in the early 80s in Greece. Soyabean oil reaches the 50% of internationally produced vegetable oils, while soyabean cake is widely used for feed. The major soyabean producers are USA (33%), Brazil (27%), Argentina (21%) and China (7%) [31]. Soyabean absorbs N_2 from the air and requires low N fertilization, No extra machinery is required for growing soyabeans. Protein content of soyabean is quite high (38%ww). The content of oil is about 18–22%ww.

Two varieties, PR9244 and PR92B63 were cultivated in 8 fields in Ipiros (Preveza, Thesprotia), West Macedonia (Amintaio), East Macedonia (Kavala, Serres) and Thrace prefectures. Some of the Western Macedonia's cultivations were destroyed due to the inappropriate application of herbicide. Pre plant N–P–K application was applied. Planting took place during May with density of 27–28 seeds/m^2 (0.45 m × 0.05 m or 0.75 × 0.03 m). Emergence occurred 5–8 days after drilling. The Herbicides used were Trifluralin (treflan), Ethafluralin (sonalan) and Bentazon (basangan), 1–3 days prior to seeding. The recorded weeds were: *D. sangualis*, *Setartia* spp, *Sorghum halepense*, *Amarathus* spp. and *Xathium strumarium*. The crop did not suffer from any diseases or enemies.

3.1.3. Sunflower

Sunflower (*Helianthus annuus*) is a typical crop of Central Macedonia and Thrace in Greece. The production reached 24.2 million tons in 2004 (170.000 ha), while sunflower reaches the 9% of the world vegetable oil production. The main sunflower producers are Russia (20%), Europe (19%), Ukraine (15%) and Argentina (13%) [31].

Sunflower showed high oil content with high concentration of oleic acid. During sunflower cultivation farmers are able to take advantage of the low fertility lands and it can be grown with limited water availability. So far sunflower is cultivated in 23 European countries including Greece [20].

Four sunflower hybrids (PR64A14, PR64A63, PR64A70 and PR63A90) were cultivated in 6 fields located from Central Macedonia (Serres) to Thrace (Evros). The planting took place from mid April–to mid May with seeding density of 4–5 seed/m^2, (0.75 m × 0.26 m or 0.75 m × 0.28 m), under non irrigated conditions or 7 seed/m^2 (0.75 m × 0.20 m) under irrigation. Emergence occurred 5–8 days after planting. Herbicides used are Trifluralin (treflan) and Ethafluralin (sonalan), The weeds that were noticed during cultivation were: *Chenopodium album*, *Amarathus* spp., *X. strumarium*, *Datura stramonium* and *Sinapi* spp. Fertilization was applied only in Alexandria and Serres (Central Macedonia) cultivation during seeding. No diseases and enemies were noticed for any of the fields cultivated.

Harvesting started late August from Thrace (Orestias) and ended within a period of 15 days. Sunflower harvesting needed special header and in regions with no previous experience of sunflower cultivation – like Alexandreia (Central Macedonia) – the harvest was delayed and finally took place with corn harvesting machines. In general, such problems should be taken into account when dealing with new crops in national agricultural activities, as lead to low productivities due to product losses.

3.1.4. Cotton

Cotton (*Gossypium hirsutum*) is a traditional spring crop in Greece and other Mediterranean countries. Cotton is cultivated for the fiber production, the fussy seeds are used for oil production and the remaining cake as feed for cattle. It is well adapted to the Greek geo-climatic conditions. Oil content of cotton seeds is rather low (∼18%ww). None the less, cotton seed oil reaches 5% of the world vegetable oil production [31].

Three cotton varieties (ST373, ST457 and ST474) were cultivated in 8 demonstration fields (Sterea Hellas, Thessaly, Central and East Macedonia, Thrace). Cotton planting lasted from 15th April until 10th of May (0.90 m × 0.035 m–0.05 m), in irrigated fields. Emergence occurred after 5–8 days. Herbicides used are Trifluralin (treflan) and Ethafluralin (sonalan). The weeds that were recorded

Table 1
New energy crops yields under real farming conditions in Greece.

Region	Rape seed yields (MT/ha)				
	Hybrids				
	PR45D01	PR46W09	PR46W10	PR46W31	PR45W04
East Macedonia (*Petrousa*)	2.21	n.a.	n.a.	2.21	n.a.
Thrace (*Isaakio*)	1.80	1.65	2.25	2.10	2.10
Cent. Macedonia (*Chalkidona*)	3.63	2.40	2.37	2.74	2.46
Peloponesus (*Messini*)	2.01	n.a.	n.a.	1.90	n.a.
Central Macedonia (*Kilkis*)	1.00	n.a.	n.a.	1.25	n.a.
Sterea Hellas (*Kopaida*)	2.10	2.31	2.11	3.45	1.87

Region	Soya seed yields (MT/ha)	
	Varieties	
	PR9244	PR92B63
Central Macedonia (*Alexandria*)	4.15	4.73
East Macedonia (*Krinides*)	2.80	4.60
East Macedonia (*Filippoi*)	2.80	3.80
Epirus (*Zervochori*)	3.30	3.95
Epirus (*Kanalaki*)	2.65	3.35
Central Macedonia (*Paralimni*)	4.25*	

* Common harvesting for both cultivations.

during cultivation are: *C. album*, *Amarathus* spp., *X. strumarium*, *D. stramonium* and *Sinapi* spp. Fertilization applied only for fields of Central Macedonia during seeding.

4. Results

4.1. Agronomic results

Table 1 presents the rapeseed cultivation obtained yield. The rapeseed hybrids PR46W31 and PR45D01 showed better results. Important parameters for rapeseed cultivation were seeding period, density, fertilization, proper harvesting time and proper harvest machinery. The rapeseed hybrid PR46W31, appeared to withstand stress (low fertility soils and low temperatures). PR46W31 stalks reached the height of 1.30 m at flowering, while during maturity was as high as 1.80 m, producing in that way larger amounts of residual biomass than the other hybrids. PR45D01 hybrid, on the other hand, led to increased production in medium and high fertility soils. It presented high tolerance to low temperatures, homogeneity in maturity stage and quick loss of seed moisture. It produced low amounts of biomass with stalks of 1 m height at the flowering period and 1.30 m during grain filling. It is flexible as far as the planting time is concerned.

Soyabean variety PR92B63 was selected for cultivation under the Greek climatologic conditions due to its high yield potential (Table 1). Soyabeans showed high protein content and satisfactory oil content. PR64A14 and PR64A63 hybrids showed larger yield (Table 2) and high adaptability in irrigated and non irrigated fields.

In line with previous experimental results, cotton (Table 2) shows high adaptation in Greek climate conditions [27]. This is especially the case for Central Greece, Thessaly and Central Macedonia (Giannitsa) and cotton potential for biodiesel and bioenergy (residues) production are in parallel with traditional fibber production, alternatives.

Overall fertilizer inputs were lower for the rapeseed than for the other crops (Table 3(b)). The other three crops required similar

Table 2
Traditional crops yields under real farming conditions in Greece.

Region	Grain sunflower yields (MT/ha)			
	Hybrids			
	PR64A63	PR64A70	PR64A14	PR63A90
Thrace (*Pentalofos*)	1.28	1.80	n.a.*	
Thrace (*Doksipara*)	2.83	4.50	4.67	2.83
Thrace (*Neochori*)	1.27	1.66	1.63	0.90
Central Macedonia (*Lagadas*)	1.31	9.10	1.02	1.22
Central Macedonis (*Mesokomi*)	4.74	4.65	4.60	4.44

Region	Grain cotton yields (MT/ha)		
	Varieties		
	ST373	ST457	ST474
Thrace (*Komotini*)	3.00	2.79	2.39
Central Macedonia (*Serres*)	3.33	2.75	2.60
Eastern Macedonia (*Drama*)	2.59	2.59	2.13
Central Macedonia (*Imathia*)	3.41	3.95	3.12
Central Macedonia (*Yianitsa*)	4.68	4.63	4.59
Thessaly (*Larissa*)	4.24	4.02	4.13
Sterea Hellas (*Messologi*)	3.90	3.80	3.60
Sterea Hellas (*Leivadia*)	5.20	4.90	5.30

* Malfunction of weight wagons.

Table 3
Grain yield, oil content and cost of production, fertilization, inputs for the energy crops in Greece.

Crop	Grain yield (MT/ha)	Moisture (%ww)	Oil content (%ww)	Oil yield (MT/ha)
(a)				
Cotton	1.58	9.93	14.79	15.9
Sunflower	2.47	7.2	42.46	10.46
Soya	3.61	13.2	20.9	7.58
Rapeseed	2.01	7.2	42.6	8.52

Residue	Fertilization		
	Nitrogen (N) (kg/ha)	Phosphorous (P) (kg/ha)	Potassium (K) (kg/ha)
(b)			
Cotton	101	31.7	33.0
Sunflower	20.0	20.0	20.0
Soya	44	57	57
Rapeseed	52	31.7	3

P and K inputs while Cotton needed more nitrogen (N) than the sunflower and soyabeans.

4.1.1. Oil production

Oil content extraction from energy crops was performed by Soxhlet method and Table 3(a) presents a comparison of the oil content (%ww) and product yield (MT/ha) of the four energy crops under study. As it is shown from Table 3(a) sunflower seems to be the most suitable solution for vegetable oil production in Greece, due to its high crop yield potential with high oil content. The rapeseed crop produced high oil yield with the lowest cost of production per hectare. Soyabean presented the highest yield of seeds (3.62 MT/ha) but the second lowest oil production. Cotton seed oil production was the least attractive option.

Cotton and sunflower crop residues could be considered as alternatives for renewable energy production in Greece, offering a higher added value to that traditional cultivations and increase farmers income. A final comparison of the above energy crops production costs is shown in Table 3(a). The cost of production per hectare for cotton and soyabeans is larger than that of the rapeseed and sunflower.

4.1.2. Characteristics of energy crop residues

The volume estimation of the residues (left over on the fields after harvesting) from the four cultivated crops are as follows: 5 MT/ha of rapeseed residues, 3 MT/ha of soya residues, 4 MT/ha of cotton residues, while sunflower presented the highest residues productivity (10 MT/ha) [32].

Rapeseed, soyabean, sunflower and cotton residues samples were analysed in the laboratory. The samples were used as received from the fields and after natural drying in the field. Ultimate analysis of rapeseed, soyabean, sunflower and cotton stalks/residues took place in a CHN-LECO 800 type analyzer, by ASDM-D 5291 method and reported in Table 4. Ultimate analysis of energy crops indicated that there are no significant differences in C, H, O content of the samples, proving the homogeneity in physicochemical characteristics of energy crops.

The proximate analysis and heating values are also included in Table 4. Both proximate and ultimate analysis was the base of a first estimation concerning energy crops suitability for exploitation by gasification. Thermogravimetric analysis (TGA) performed in a TA Instruments 2960 type thermogravimetric analyzer for determination of the proximate analysis of the energy crop residues. Table 4 presents the proximate analysis of rapeseed, soyabean, sunflower and cotton stalks, according to which all present low moisture contents (>20%ww), while sunflower (5.08%ww) presents the highest ash content and cotton the lowest (3.10%ww).

A bomb calometer and ASDM-D 4809 used in order to estimate the calorific value of residues. Soyabean showed higher heating value than the other three residues (6125.79 kcal/kg), while cotton presented comparable energy content with rapeseed. Sunflower had the lowest calorific value of all. The higher heating content of soya and rapeseed residues might be attributed to their oily nature, offering them an advantage in calorific value.

According to ultimate and proximate analysis of residues all are suitable to be exploited by gasification, aiming at increasing the energy crops added value and contribution to renewable energy production commitments of Greece; thus the potential of energy production from the remained residues on fields, leaving unexploited their attractive energy content, should not be underestimated.

It has to be pointed out that cotton and sunflower crops are widely known in Greece with a very good adaptability behaviour in Northern-Central Greece and Thrace, while they are cultivated

Table 4
Ultimate and proximate analysis of energy crop residues.

Residue	Rapeseed	Soya	Sunflower	Cotton
Ultimate analysis (%ww, dry)				
C	44.52	43.59	42.60	44.29
H	5.53	5.60	5.47	5.57
O*	49.37	50.46	51.74	49.4
N	0.58	0.35	0.19	0.74
HHV (kcal/kg)	5,553.31	6,125.79	5,375.46	5,547.62
LHV (kcal/kg)	5,269.49	5,982.76	5,094.67	5,261.80
Proximate analysis (%ww, dry)				
Moisture (%ww)	2.01	2.24	1.68	2.65
Ash (%ww)	3.87	3.93	5.08	3.10
Volatiles (%ww)	91.46	90.74	88.52	91.58
Fixed carbon (%ww)	2.66	3.09	4.72	2.67

* By difference.

Table 5
Comparison of production cost and market value of energy crop seeds in Greece.

Region	Production cost (€/kg)	Tentative farmer price (€/kg)	Notice
Cotton grain			
Central Macedonia (*Yiannitsa*) Aver. yield: 4.63 MT/ha	0.38	0.33	High inputs irrigated
Thrace (*Komotini*) Aver. yield: 2.73 MT/ha	0.38	0.30	Medium inputs irrigated
Soya grain			
Central Macedonia (*Alexandria*) Aver. yield: 4.44 MT/ha	0.32	n.a.*	High inputs and fertility
Eastern Macedonia (*Krinides*) Aver. yield: 3.70 MT/ha	0.26		Organic soil, medium inputs
Central Macedonia (*Paralimni*) Aver. yield: 4.24 MT/ha	0.24		High inputs and fertility
Rapeseed grain			
Thrace (*Pentalofos*) Aver. yield: 1.98 MT/ha	0.20	0.25	Low inputs, no irrigation
Central Macedonia (*Chalkidona*) Aver. yield: 2.72 MT/ha	0.18	0.25	High inputs, medium irrigated
Sunflower grain			
Thrace (*Pentalofos*) Aver. yield: 1.540 MT/ha	0.29	0.25	No Irrigated, low inputs
Thrace (*Doksipara*) Aver. yield: 3.71 MT/ha	0.12	0.25	High fertility, low inputs, limited irrigation
Thrace (*Neochori*) Aver. yield: 1.34 MT/ha	0.29	0.25	No Irrigated, low inputs
Central Macedonia (*Lagadas*) Aver. yield: 1.13 kg/ha	0.19	0.25	No Irrigated, low inputs
Central Macedonia (*Mesokomi*) Aver. yield: 4.61 MT/ha	0.21	0.25	High fertility and inputs, irrigated

* Soya is imported in Greece and it has not a commercial value.

almost exclusively for cotton fibber and sunflower oil, respectively [32]. Cotton and sunflower residues exploitation for energy production can offer an added value to farmers' income. Rapeseed, on the other hand, is a crop rich in oil (like sunflower) and is usually used for biodiesel production but soya is advantageous when taking into consideration its proteinic content [32] and thus could be used as animal feed.

A final comparison of the above energy crops production costs is shown in Table 3a. The cost of production per hectare for cotton and soyabeans is larger than that of the rapeseed and sunflower.

An important criterion that determines the ability of energy crop residues exploitation by thermochemical treatments is moisture content and C/N ratio. Moisture content of residues lower than <50% and C/N >30 indicated primarily the viability of exploitation of the selected residues by gasification. For higher moisture contents and C/N ratios any biomass is better to be exploited by biochemical methods (fermentation, aerobic or anaerobic digestion).

4.2. Gasification of residues

A laboratory scale fixed bed gasifier was used in order to perform the gasification experiments and a detailed description of the reactor and gasification methodology can be found elsewhere [32]. Air was used as the gasification medium at lower amounts than stoichiometric in order to avoid complete combustion.

In the present work gasification experiments were performed by varying temperature from 750 °C to 950 °C. Studying the gasification gas composition it was noticed that low temperature gasification $T = 750\,^{\circ}C$, enhanced gasification gas production, while higher temperature ($T = 950\,^{\circ}C$) produced a gas enriched in H_2 and CO (syngas). At $T = 750\,^{\circ}C$, sunflower produced a gasification gas with increased H_2 concentration, while at $T = 950\,^{\circ}C$ cotton stalks led to a higher heating value gas of all.

LHV_{gas} of gasification gas was calculated and found that high temperature of gasification increased the LHV_{gas} of crop stalks producing medium heating value (8–10 MJ/Nm^3) gas. Soya and rapeseed gave higher LHV_{gas} at $T = 950\,^{O}C$, while cotton and sunflower at lower temperature $T = 850\,^{O}C$, indicating the ability of low cost energy production from those residues.

Especially as it concerns cotton and sunflower, two well known and widespread crops in Greece, it seems that alternative energy production of their residues by low temperature gasification might consist an environmental friendly and CO_2 sequestrating energy production alternative.

4.3. Economic aspects

The production cost of 1 kg of product is presented in Table 5, as well as their market value. Sunflower and rapeseed presented the lowest cost of production, while cotton the highest. The additional exploitation of the residues with gasification would lead to higher energy production efficiencies, cut down the energy crop production cost, and raise the interest in traditional and new cultivations in Greece. Extra energy production could contribute to the country's renewable energy commitments.

Table 6 presents an estimation of the energy saving potential of energy crop residues in Greece per ha of cultivated land, indicating the ability of saving 12.4 Toe/ha. Additionally, the alternative energy production route by gasification (Table 6) could also lead to an easier to exploit medium calorific value gas in integrated energy production systems, offering higher efficiencies than combustion.

4.4. Sustainability issues

The results of the present study indicated that the harvesting technique and the timing of energy crops harvesting differ from the cereals production.

It is well known that fresh-water use in agriculture is a critical parameter because water is already scarce in some regions of the Mediterranean countries and threatens some agriculture regions in Greece. Moreover, under the impact of climate change the risk of water stress could decrease substantially by the end of the century.

Table 6
Calorific content of (a) energy crop residues and (b) syngas and energy saving potential (Toe).

Energy crop	Residues productivity (kg/ha)	Heating value (kcal/kg)	Biomass energy (Mcal/ha)	Energy saving (Toe/ha)
(a)				
Rapeseed	5000	5,553.31	27,766.5	2.8
Soya	3000	6,125.79	18,377.4	1.8
Sunflower	10,000	5,575.46	55,754.6	5.6
Cotton	4,000	5,547.62	22,190.5	2.2
Tons of oil equivalent (Toe/ha)				12.4

Residue	$Nm^3{}_{gas}$/kg	kg/ha	$Nm^3{}_{gas}$/ha	LHV_{gas} (MJ/Nm^3)	Syngas (MJ/ha)	E_{th} (Toe/ha)
(b)						
Rapeseed	0.59	5000	2950	9.01	26,579	0.63
Soya	0.47	3000	1410	9.08	12,803	0.30
Sunflower	0.51	10,000	5100	7.97	40,647	0.97
Cotton	0.61	4000	2440	9.81	23,936	0.57
Tons of oil equivalent (Toe/ha)						2.47

From that point of view, water demand for energy crops cultivation and bioenergy production might place an additional barrier on water availability and induce increased competition over water resources. Despite the above barriers, bioenergy demand can lead to new opportunities to develop strategies to adapt to climate change in agriculture. The possibility to integrate the cultivation of new types of energy crops within expanded agricultural systems in a modified water resource context presents challenges, as well as opportunities in the development of water and land use strategies (http://www.wbgu.de/wbgu_jg2008_ex02.pdf).

On the other hand, the replacement of conventional fuels with biofuels does not necessary guarantee the success of the attempt. Indeed, in order to convert the chemical energy of biomass into useful energy large amounts of materials and external energy are often required for cultivation, harvesting, storage and final exploitation in a form suitable for end using; thus, from a wider point of view, cultivation choices, techniques and end users should maximize farmers income, crop yields and quality, promote energy and chemicals saving, reduce manpower, diminish negative effects on soil, water and air by taking into consideration that a successful embodiment of energy crops in a local agriculture system must fall within the parameters of sustainable agriculture.

5. Conclusions

Integrated management of energy crops for biofuels and bioenergy production is challenging taking into consideration Greece's commitments towards the goal of 20–20–20 in 2020. Rapeseed and soyabean presented promising results. However, their large scale cultivation lacks agronomic experience. The integrated management of cotton and sunflower, already established crops in Greece, seems sustainable. It could increase the farmer's income and result in new job positions in rural areas. Finally, it can contribute to the cohesion of agricultural, energy and environment policy in Greece.

Some specific conclusions concerning crop prospects and management tips are the following:

(a) For rapeseed
- Large variability in yield was recorded among the growing environments.
- Experience and better crop management will result in larger yields than the current ones.
- Planting of rapeseed at the regions of Macedonia and Thrace has to be performed before the 25th of October. If the weather is dry in autumn irrigation is necessary for successful stand establishment.
- Winter cereals planters are not recommended.
- Temperature is quite high during May and June in Greece and seeds mature quickly. Showers and hail threaten production before harvest.
- The cereals header is not the best choice. Proper management of the current harvest machinery and low harvest speed decreased the loss of production during harvest.
- Herbicides application pre plant or pre emergence is necessary.
- Aphids seem to be the major entomological issue.
- Overall, the rapeseed crop produced high volume of oil per hectare with minimal cost.

(b) Soyabeans
- High yield was obtained with no extra care or investment by the farmers.
- High input areas raised soyabean cultivation cost in some cases.
- The high price of soyabean-flour, the quality of the Greek production, and the increased vegetable oil demands may lead Greek soyabean production to competitive levels so as to make the local production economically viable especially for North Greece.

(c) Sunflower:
- Large variability in yield was recorded among the growing environments.
- High yield of seed and oil are related to high soil fertility and increased inputs.
- Sunflower oil yield was reduced with late planting and low inputs.
- Large volume of sunflower residues may offer an added value in case of their exploitation for bioenergy production.
- The average yield of 1 MT/ha of oil is confirmed as a national average point of reference.

(d) Cotton
- High land rent, and generally high cost of inputs make cotton cultivation too expensive for many Greek growers.
- It was difficult to achieve high crop and oil yield in parallel with low inputs.
- As the crop moves up the North the average seed cotton yield declines.
- Cotton residues exploitation for solid and liquid biofuels production along with elevated oil content (>18%ww) may add a higher value and give a new perspective in cotton cultivation in Greece aiming at the biofuel market.

Added value of energy crop residues exploitation has not yet been attempted by thermochemical treatment in Greece and a valuable energy carrier (stalks) remains unexploited on fields. Proximate and ultimate analysis of energy crop residues indicated their

suitability for thermochemical valorisation by pyrolysis and gasification that under proper management could lead to an increase in farmers' income and support this indigenous cultivation in Greece with lower subsidies than the past.

Taking into consideration that there is already a fast development of the solid and liquid biofuels market the perspective of vegetable oil production from indigenous energy crops, as well as exploitation of their solid residues, seems attractive. Furthermore the crop residues for energy production are viable by gasification. The vegetable oil and the related by product and residues production can support (a) the bio diesel production in Greece (b) the farmers income and (c) the increase contribution of advanced biofuels production in Greece.

Further investigation especially of the newer crops in Greece is needed and a life cycle analysis that will be performed soon, in order to claim the sustainability of bioenergy and biofuel chains from energy crops in Greece. Further investigation of the energy crops exploitation in Mediterranean countries, in relation with issues concerning land use, water supply and bioenergy use under changing climate conditions must be addressed.

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